CLAIMS

What is claimed is:

1. A method of determining diffusion and relaxation characteristics about a fluid in an earth formation using nuclear magnetic resonance (NMR) comprising:

   (a) applying a static magnetic field to the earth formation, said applied static magnetic field producing an internal field gradient;

   (b) applying a sequence of radio frequency (RF) pulses to said earth formation;

   (c) detecting magnetic resonance signals resulting from said first sequence; and

   (d) processing said detected signals for determining said diffusion and relaxation characteristics, said determination taking into account said internal field gradient.

2. The method of claim 1 wherein said sequence of RF pulses further comprises:

   (A) a first sequence of RF pulses associated with a first signal at a first field gradient, and

   (B) a second sequence of RF pulses associated with a second signal at a second field gradient different from said first field gradient;

   wherein said signals comprise said first signal and said second signal..

3. The method of claim 2 wherein said first and second field gradients correspond to different regions of examination in said earth formation.

4. The method of claim 2 wherein said first and second pulse sequences each comprise at least one initial pulse, a first portion that follows the at least one initial magnetic field pulse, and a second portion that follows the first portion such that the second portion refocuses a last echo of the first portion.

5. The method of claim 2 wherein

(i) said first portion comprises a modified CPMG sequence including a plurality of refocusing pulses with a tipping angle less than 180^0 and having a first time interval between adjacent refocusing pulses of said first portion, and

(ii) said second portion comprises a plurality of refocusing pulses having a second time interval between adjacent refocusing pulses.

6. The method of claim 2 wherein said first portion comprises one of (i) an inversion recovery sequence, (ii) a driven equilibrium sequence, and, (iii) a CPMG sequence.

7. The method of claim 5 further comprising applying an echo train correction to said first and second signal.

8. The method of claim 5 further comprising at least one additional repetition of (A) and (B) for a different value of said first time interval.

9. The method of claim 5 further comprising repeating (i) for at least one additional value of a time interval between refocusing pulses of said CPMG sequence, said additional value being substantially equal to said second time interval.

10. The method of claim 1 further determining at least one of (i) a total porosity, (ii) clay bound water, (iii) bound volume irreducible, (iv) gas saturation, and, (v) oil saturation.

11. The method of claim 2 wherein said first sequence is of a form:

$$W - 90_{\pm x} - TE_{long}/2 - \beta_{Y1} - TE_{long}/2 - echo_1 - TE_{long}/2 - \beta_{Y1} \\ - TE_{long}/2 - echo_2 - (TE/2 - \beta_{Y2} - TE/2 - echo)_j$$

where j is an echo number in a train, W is a wait time, TE_{long} is a diffusion editing spacing, TE is the Carr-Purcell spacing, $90_{\pm x}$ and β_{Y1} (or β_{Y2}) are RF pulses providing rotation angles of 90 and the β_{Y1}(or β_{Y2}) degrees of a magnetization vector.

12. The method of claim 1 wherein processing said first and said second signal further comprises, for said first field gradient and said second gradient, inverting said first and said second signals, to obtain an equivalent amplitude spectrum of a T_2 distribution.

13. The method of claim 12 wherein said processing said first and said second signal further comprises inverting a T_2 distribution to obtain a generalized parameter.

14. The method of claim 13 wherein said generalized parameter $Z_i^{(j)}$ has a form:

$$Z_i^{(j)} = \frac{C}{\gamma^2 G_e^2 D_i^j}$$

where C is a constant, γ is a gyromagnetic ratio, G_e is the effective field gradient, and D_i^j is a diffusion coefficient.

15. The method of claim 13 wherein said processing said first and said at least one additional signal further comprises inverting a plurality of said generalized parameters.

16. The method of claim 12 wherein at least one component of said equivalent amplitude spectrum further comprises a plurality of diffusion components.

17. The method of claim 11 further comprising at least one additional repetition of (b) and (c) for a different value of TE_{long}.

18. The method of claim 2 wherein said first pulse sequence is of a form:

$$180-\tau_1-90_{\pm x}-\left[TE/2-\beta_Y-TE/2-echo\right]_j$$

wherein 180 is a 180^0 tipping pulse, τ is a wait time, TE is the Carr-Purcell spacing, $90_{\pm x}$ and β_Y are RF pulses providing rotation angles of 90^0 and β of a magnetization vector

19. The method of claim 18 further comprising at least one additional repetition of (A) and (B) for a different value of τ.

20. An apparatus for determining diffusion and relaxation characteristics about a fluid in an earth formation comprising:

(a) a magnet on a nuclear magnetic resonance (NMR) sensor conveyed in a borehole in said earth formation, said magnet producing a static magnetic field to the earth formation with an internal field gradient therein,;

(b) a transmitter on said NMR sensor for applying a sequence of radio frequency (RF) pulses to said earth formation;

(c) a receiver on said NMR sensor for detecting magnetic resonance signals resulting from said first sequence; and

(d) a processor for determining from said detected signals said diffusion and relaxation characteristics, said determination taking into account said internal field gradient.

21. The apparatus of claim 20 wherein said transmitter applies:

(A) a first sequence of RF pulses associated with a first signal at a first field gradient, and

(B) a second sequence of RF pulses associated with a second signal at a second field gradient different from said first field gradient;

wherein said signals comprise said first signal and said second signal..

22. The apparatus of claim 21 wherein said first and second field gradients correspond to different regions of examination in said earth formation.

23. The apparatus of claim 21 wherein said first and second pulse sequences each comprise at least one initial pulse, a first portion that follows the at least one initial magnetic field pulse, and a second portion that follows the first portion such that the second portion refocuses a last echo of the first portion.

24. The apparatus of claim 21 wherein

(i) said first portion comprises a modified CPMG sequence including a plurality of refocusing pulses with a tipping angle less than 180^0 and having a first time interval between adjacent refocusing pulses of said first portion, and

(ii) said second portion comprises a plurality of refocusing pulses having a second time interval between adjacent refocusing pulses.

25. The apparatus of claim 21 wherein said first portion comprises one of (i) an inversion recovery sequence, (ii) a driven equilibrium sequence, and, (iii) a CPMG sequence.

26. The apparatus of claim 24 wherein said processor further applies further an echo train correction to said first and second signal.

27. The apparatus of claim 24 wherein said transmitter further performs at least one additional repetition of (A) and (B)for a different value of said first time interval.

28. The apparatus of claim 24 wherein said processor further repeats (i) for at least one additional value of a time interval between refocusing pulses of said CPMG sequence, said additional value being substantially equal to said second time interval.

29. The apparatus of claim 20 wherein said processor further determines at least one of (i) a total porosity, (ii) clay bound water, (iii) bound volume irreducible, (iv) gas saturation, and, (v) oil saturation.

30. The apparatus of claim 21 wherein said first sequence is of a form:

$$\begin{aligned} W - 90_{\pm x} - TE_{long}/2 - \beta_Y - TE_{long}/2 - echo_1 - TE_{long}/2 - \beta_Y \\ - TE_{long}/2 - echo_2 - \left(TE/2 - \beta_Y - TE/2 - echo\right)_j \end{aligned}$$

where j is an echo number in a train, W is a wait time, TE_{long} is a diffusion editing spacing, TE is the Carr-Purcell spacing, $90_{\pm x}$ and β_Y are RF pulses providing rotation angles of 90^0 and the β of a magnetization vector.

31. The apparatus of claim 20 wherein said processor further obtains an equivalent amplitude spectrum of a T_2 distribution.

32. A system for use in a borehole in an earth formation comprising:

(a) a conveyance device for conveying a nuclear magnetic resonance (NMR) sensor into said borehole;

(b) a magnet on said NMR) sensor, said magnet applying a static magnetic field in said earth , said static magnetic field having an internal gradient;

(b) a transmitter on said NMR sensor for applying radiofrequency (RF) magnetic field pulses to said formation and producing signals resulting from a T_2 distribution spectrum of said earth formation, at least one component of said T_2 spectrum further comprising a plurality of diffusion coefficients;

(c) a receiver on said NMR sensor for receiving said produced signals;

(d) a processor for processing said received signals and determining therefrom said T_2 distribution and said plurality of diffusion coefficients, said determination accounting for said internal gradient.

33. The system of claim 32 wherein said conveyance device is one of (i) a wireline, (ii) a drillstring, and, (iii) coiled tubing..

34. A method of analyzing an earth formation comprising:

(a) applying a static magnetic field to the earth formation, said applied static magnetic field producing an internal field gradient in said earth formation;

(b) applying a first sequence of radio frequency (RF) pulses to said earth formation and obtaining a first signal associated with a first value of a field gradient;

(c) applying a second sequence of radio frequency (RF) pulses to said earth formation and obtaining a second signal associated with a second value of a field gradient; and

(d) processing said first and second signals for determining at least one of (A) a diffusion characteristic of said earth formation, and, (ii) a relaxation characteristic of said earth formation, said determination taking into account said internal field gradient.

35. The method of claim 34 wherein said first and second field gradients correspond to different regions of examination in said earth formation.

36. The method of claim 34 said first and second pulse sequences each comprise at least one initial pulse, a first portion that follows the at least one

initial magnetic field pulse, and a second portion that follows the first portion such that the second portion refocuses a last echo of the first portion.

37. An apparatus for use in a borehole in an earth formation comprising:

(a) a magnet for applying a static magnetic field to the earth formation, said applied static magnetic field producing an internal field gradient in said earth formation;

(b) a transmitter for applying a first sequence and a second sequence of radio frequency (RF) pulses to said earth formation;

(c) a receiver for obtaining a first signal and a second signal resulting from said first and second sequence of RF pulses, said first and second signals associated with a first and second value of a field gradient in said earth formation; and

(d) a processor for determining from said first and second signal at least one of (A) a diffusion characteristic of said earth formation, and, (ii) a relaxation characteristic of said earth formation, said determination taking into account said internal field gradient.

38. The apparatus of claim 37 wherein said first and second field gradients correspond to different regions of examination in said earth formation.

39. The apparatus of claim 37 said first and second pulse sequences each comprise at least one initial pulse, a first portion that follows the at least one

initial magnetic field pulse, and a second portion that follows the first portion such that the second portion refocuses a last echo of the first portion.

40. The apparatus of claim 37 further comprising a conveyance device selected from (i) a wireline, (ii) a drilling tubular, and, (iii) coiled tubing.

41. The method of claim 39 wherein said first portion comprises one of (i) an inversion recovery sequence, (ii) a driven equilibrium sequence, (iii) a CPMG sequence, and, (iv) a modified CPMG sequence having a refocusing pulse with a tipping angle less than 180°.